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SOIL SALINITY DETECTION



Principal Investigator: Craig L. Wiegand

Other Investigators: Arthur J. Richardson
Harold W. Gausman
Ross W. Leamer
Alvin H. Gerbermann
James H. Everitt
Jose A. Cuellar

Agricultural Research Service
U.S. Department of Agriculture
P. O. Box 267
Weslaco, TX 78596

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16. Abstract

Growth forms and herbage biomass production varied considerably with soil salinity on range sites in Starr County, Texas. Differentiation between saline and non-saline rangelands may be possible using SKYLAB satellite black-and-white film because of more bare soil background showing through vegetation in saline areas. Differentiation among saline and non-saline cultivated soil sites in Cameron County, Texas, was not possible using black-and-white or color film, but vegetation and bare soil MSS digital data difference or ratio may be a good indicator of salinity levels at aircraft and satellite altitudes. MSS infrared wavelengths were superior to visible wavelengths for soil salinity detection. Thus, aircraft or spacecraft information may be useful for detection of saline soil in rangeland areas (Starr County, Texas) by measuring the bare soil showing through vegetal areas, and in cultivated areas (Cameron County) by measuring contrast between the vegetation and adjacent bare soil. Cost/Benefit studies indicate that satellite information may give an overall economic saving to saline soil management compared with aircraft or photointerpretive information.

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PREFACE

The research by the U.S. Department of Agriculture (USDA) at Weslaco, Texas, with aircraft, SKYLAB, and LANDSAT-1 data had the objective of detecting and surveying saline soil areas in Starr and Cameron Counties in Texas. Several substudies relating to this objective were: (1) relate vegetation conditions to soil salinity, (2) relate SKYLAB Earth Terrain and multispectral camera imagery to soil salinity, and (3) relate multispectral scanner data collected by aircraft, SKYLAB, and LANDSAT-1 to soil salinity. A saline soil map for Cameron County was produced to study the geographical extent of saline soil areas. The potential of aircraft or spacecraft data to provide information useful for operational saline soil management in the Lower Rio Grande Valley area was assessed. The procedures used in this study may lead to a useful saline soil detection and delineation scheme, and merit further testing.

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# ABBREVIATIONS

| | |
|---|---|
| ANOV | Analysis of Variance |
| CCT | Computer Compatible Tape |
| DMRT | Duncan's Multiple Range Test |
| ECe | Electrical Conductivity expressed in millimhos/centimeter (mmhos/cm) |
| ETC | Earth Terrain Camera |
| LANDSAT-1 | First Earth Resources Technology Satellite |
| m | Meter |
| MCF | Multispectral Camera Facility |
| MSS | Multispectral Scanner |
| NASA | National Aeronautics and Space Administration |
| USDA | United States Department of Agriculture |

# INTRODUCTION

The work planned under this contract had the objective of detecting and surveying saline soil areas in Starr and Cameron Counties in Texas using aircraft, SKYLAB, and the first Earth Resources Technology Satellite (LANDSAT-1) data. This objective can logically be grouped into the following substudies:

1. Relate vegetation conditions (woody species composition and canopy cover) to soil salinity of seven Starr County range sites.

2. Relate S190A multispectral camera (MCF) imagery to soil salinity of seven Starr County range sites.

3. Relate S190B Earth Terrain Camera (ETC) imagery to soil salinity of eight saline soil areas in Cameron County.

4. Relate data from various MSS sensor systems to soil salinity of eight saline soil areas in Cameron County.

Guidelines considered for evaluation of these substudies are:

a. What combination of spectral bands provides the best detection of soil salinity levels?

b. Can aircraft or spacecraft data provide information useful for operational saline soil management in the Rio Grande Valley area?

c. What are the cost/benefits to provide aircraft or spacecraft information useful for saline soil management?

# PROCEDURES

## Ground Truth Methods Used in Starr County

This study was conducted along a 15-mile north to south flight line in Starr County, Texas (Fig. 1). The southern end of this line is located approximately 4 miles north of Roma. Gould (1969) included this area in the South Texas Plains vegetational area.

The land use along this flight line is rangeland. The topography is nearly level to gently undulating. A few areas are hilly and broken by caliche and gravel ridges.

The climate of this area is mild with short winters and relatively warm temperatures throughout the year. Summer temperatures and evaporation rates are high. Average annual rainfall is approximately 17.3 inches. Heaviest rains occur in May and September (Texas Almanac, 1974). There are often months when no precipitation occurs.

Thompson et al. (1972) named seven soil types and six range sites for this study area:

| Soil Types | Range Site |
|---|---|
| Catarina soils | Saline clay (saline) |
| Copita fine sandy loam | Gray sandy loam (non-saline) |
| Garceno clay loam | Clay loam (non-saline) |
| Maverick soils, eroded | Rolling hardland (saline) |
| Montell clay, saline | Saline clay (saline) |
| Ramadero loam | Ramadero (non-saline) |
| Zapata soils | Shallow ridge (non-saline) |

Three replications each of the seven soil types were chosen on the basis of their area on the ground being large enough to be discernible on spacecraft imagery. Thus, a total of 21 sample sites were chosen along the flight line.

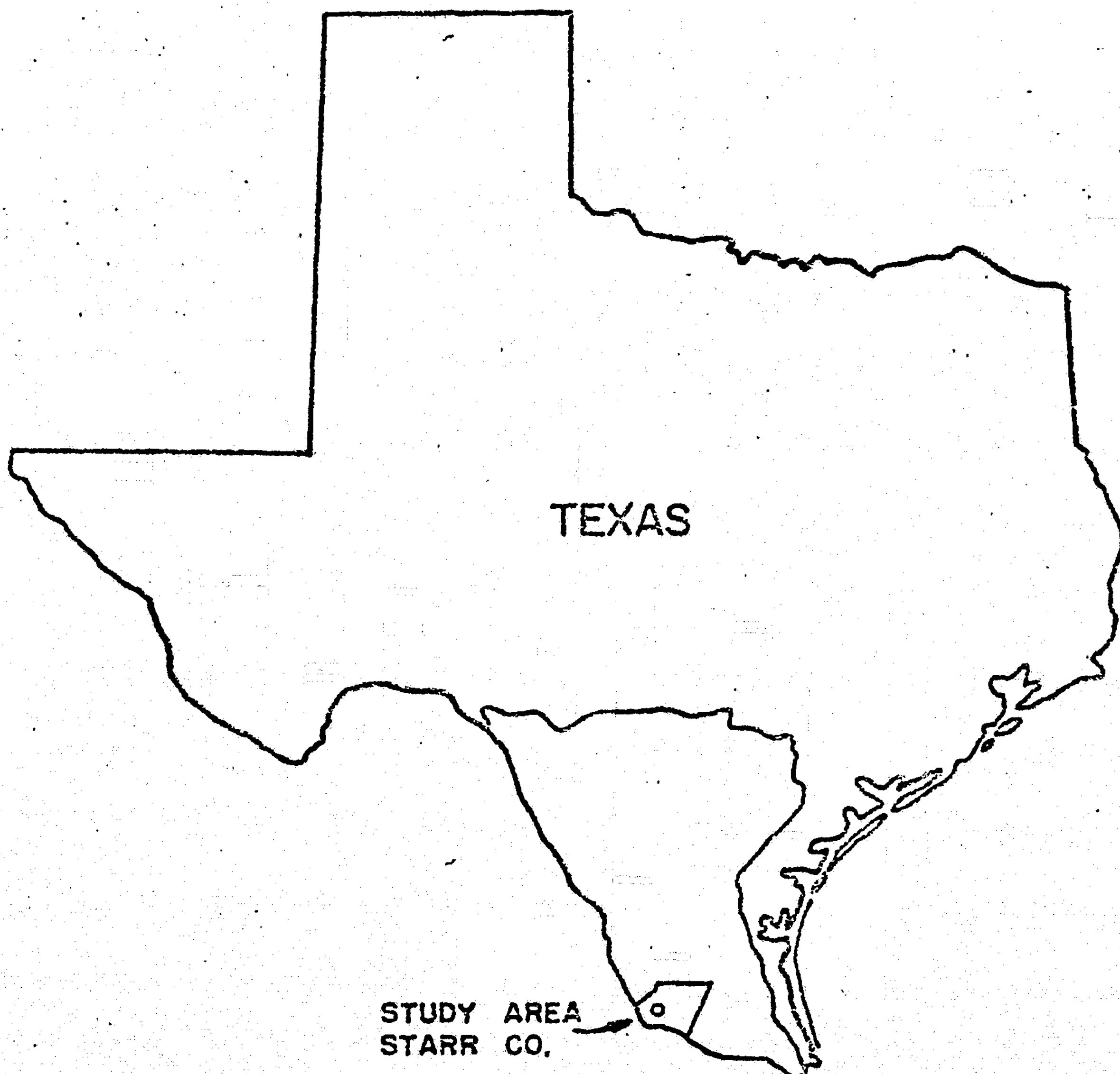


Fig. 1. Location of saline soil study area in Starr County, Texas.

Ground truth data were collected for each of the sample sites. Soil samples were taken from each site in order to determine the electrical conductivity (ECe) of each soil type. Samples were taken at soil depths of 0 to 15, 15 to 30, 30 to 45, and 45 to 60 cm. The majority (16) of the 21 sample sites were "brush-infested native rangeland;" however, the brush had been partially controlled on five sites (2 gray sandy loam, 2 clay loam, 1 Ramadero) and the range reseeded to "introduced grasses." Vegetational composition of the different range sites was determined by the line transect method (Canfield, 1941) for woody plants, and the point frame method (Tothill and Peterson, 1962) for herbaceous plants. The Catarina soils and Montell clay soils are saline soils that have the same associated range site (Saline clay site). However, since these were two separate soil types among the sample sites, they were treated as separate range sites in describing their botanical composition.

Electrical conductivity (ECe) of the saturated soil extracts of each of the seven soil types was performed according to the method of Richards (1954).

<u>Optical Density Data Collected in Starr County</u>

The SKYLAB imagery, from S190A MCF was exposed at 2:45 p.m. central standard time on May 30, 1973 (orbit 1, SL2), at a scale of 1:3,000,000. Table 1 lists the film/filter combinations and the wavelengths used.

Film density readings were made with a Joyce Loebl and Company[1] (England) microdensitometer equipped with an automatic scanning attachment made by Tech/Ops (Burlington, Mass., USA). Density readings were made on the MCF films listed in Table 1. Color density readings were made with four different lights: white (no filter), red (Wratten 92 filter), green (Wratten 93 filter), and blue (Wratten 94 filter). Black-and-white film density readings were made with white light only. Each density reading represents the density of 0.0015 sq. mm. of film, and readings were made at 100 per 2.54 mm. on the films.

The various sample sites were located on an isodensitracing (gray map) of each film type.

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1 Mention of company or trademark is for the readers' benefit and does not constitute endorsement of a particular product by the U. S. Department of Agriculture over others that may be commerically available.

Table 1. Film/filter combinations, sensitive wavelengths, and dates of data acquisition for the SKYLAB S190A multispectral camera and the S190B Earth Terrain Camera.

| Wavelength (μm) | Film | Filter (NASA designation) |
|---|---|---|
| | S190A Multispectral Camera (5/30/73) | |
| 0.50 - 0.60 | Pan-X B & W (SO-022) | AA |
| 0.60 - 0.70 | Pan-X B & W (SO-022) | BB |
| 0.70 - 0.80 | IR B & W (EK-2424) | CC |
| 0.80 - 0.90 | IR B & W (EK-2424) | DD |
| 0.50 - 0.88 | IR Color (EK-2443) | EE |
| 0.40 - 0.70 | HI - RES color (SO-356) | FF |
| | S190B Earth Terrain Camera | |
| 0.50 - 0.70 | Hi defin B&W (EK-3414) (11/29/73) | 5 (Wratten 12) |
| 0.40 - 0.70 | HI - RES color (SO-242) (12/5/73) | 2 |

Density readings were grouped by soil type and associated range site, color light density, and film type, and read into a computer by sampling sites. To eliminate unusually high or low density readings caused by clouds or man-made objects, a mean and standard deviation were calculated and the computer then eliminated all density readings outside of the interval of the mean ± one standard deviation and then recalculated a mean for each sample site.

The mean density readings for each sampling site were used as replications for each soil type and range site. For color and color infrared 190A film, an analysis of variance was calculated for each color light density; one analysis of variance (ANOV) was calculated for each of the black-and-white MCF films.

Duncan's Multiple Range Test (DMRT) (Duncan, 1955) was used to make all possible mean comparisons ($P < .05$) among soil types and their associated range sites. This standard statistical test is performed on ranked means It is a procedure for systematically comparing each mean with all other means. One calculates the standard error for all the observations represented by the ranked means. He multiplies this standard error by a factor (studentized range) that increases as the means under comparison become further separated in the ranking and decreases as the number of means in the comparison increases to obtain the "least significant ranges." (The factors are tabulated in reference tables.) One subtracts the appropriate least significant range from the difference for the mean comparison being conducted. If this difference is equal to or larger than the mean difference being compared, then the two means are significantly different. However, if the range is larger than the mean difference, then the two means are not significantly different. In tabulations, the results of DMRT are typically indicated by placing the same letter in vertical alignment after all means that do not differ Thus any group of means followed by the same letter--"a" for instance--do not differ statistically. Conversely, means being compared that are not followed by the same letter are statistically different.

## Ground Truth Methods Used in Cameron County

Table 2 briefly describes the soils in the Cameron County saline study site. These soils were sampled, oven-dried, and passed through a 2-mm sieve. Their particle size distribution was made according to the Bouyoucos (1936) method, and their salinity levels were determined by making electrical conductivity readings (ECe) on saturated extracts (Richards, 1954).

Because there was poor correlation between ECe readings and particle size distribution, the test site was arbitrarily divided in areas (eight areas from A through H) of low, medium, and high salinity levels based on ECe readings in mmhos/cm as shown in Fig. 2.

Table 2. Descriptive summary of soils in the Cameron County saline study area.

| Number of soil series per soil type | Soil type | Munsell color[1] (dry soil) |
|---|---|---|
| 2 | Sandy clay loam | 10 YR 3/2 |
| 3 | Clay loam | 10 YR 5/1 |
| 5 | Fine sandy loam | 10 YR 4 or 5/2 |
| 1 | Clay | 5 YR 6/1 |
| 4 | Clay | 10 YR 4 or 5/1 or 2 |
| 3 | Silty clay | 10 YR 4 or 5/1 |
| 2 | Silty clay loam | 10 YR 4 or 6/2 |

[1] Munsell color data taken from Munsell Soil Color Charts, Munsell Color Company, Inc., 1954 Edition. YR = hue, number preceding / is value (brightness); number following / is chroma (color saturation). The color of the soils essentially ranged from light gray to dark brown.

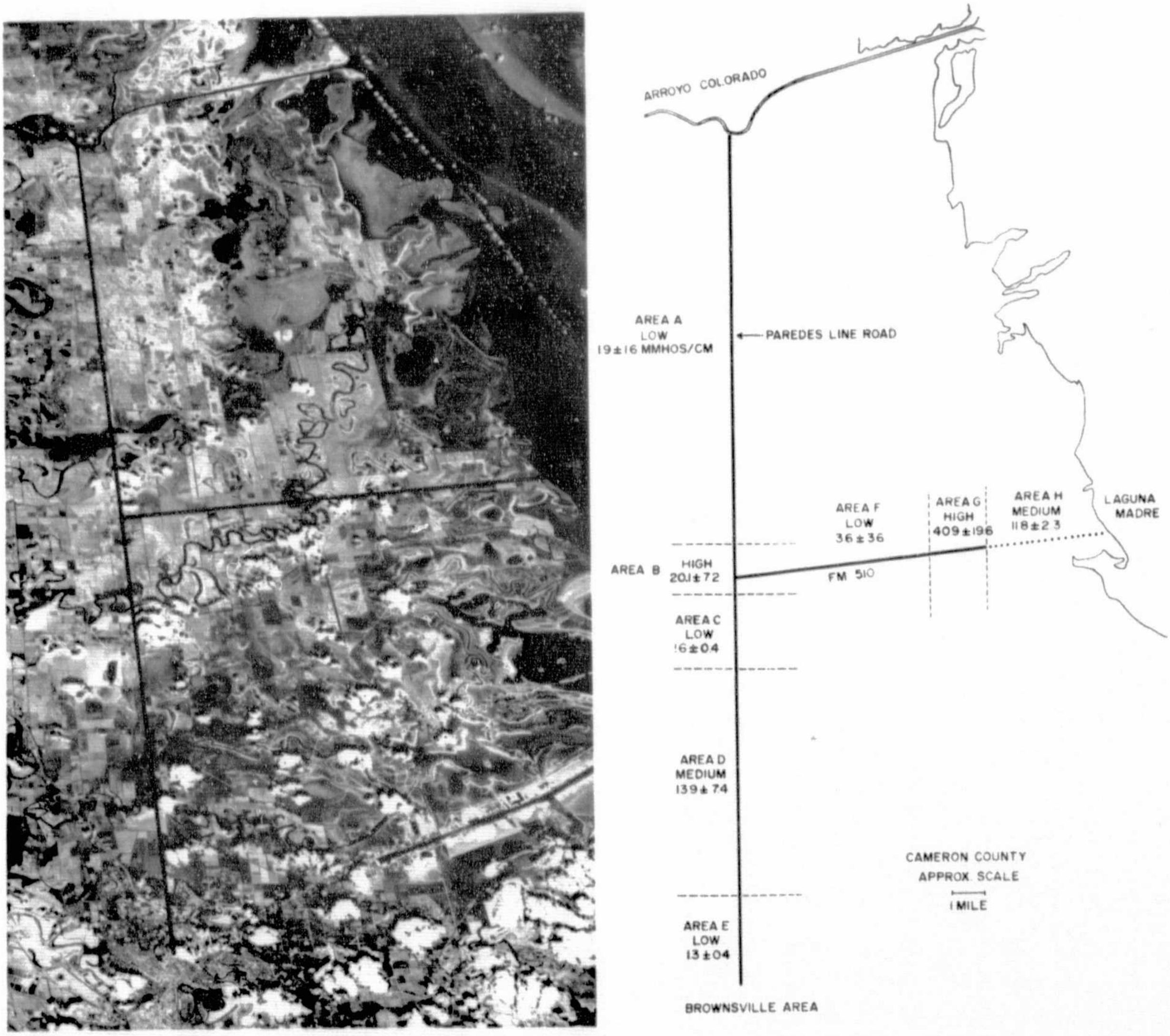



Fig. 2. Saline soil study site in Cameron County showing location of electrical conductivity measurements (mmhos/cm) for eight saline soil areas. The study site is located on Paredes Road and Farm Road 510 and was used for relating soil salinity measurements to the black-and-white imagery (EK-3414) from the S190B Earth Terrain Camera (shown), as well as to color film (SO-242) and S192 multispectral scanner data.

Optical Density Data Collected in Cameron County

Film density readings were made with a Joyce Lobel and Company[1] (England) microdensitometer equipped with an automatic scanning attachment made by Tech/Ops (Burlington, Mass. USA). Density readings were made on aerial color SO-242 positives (December 5, 1973, Orbit 61, SL4) and on black-and-white EK-3414 film negatives (see Fig. 3) (November 29, 1973, Orbit 53, SL4) from S190B ETC imagery. Film spectral sensitivity range was 0.4 to 0.7 μm (SO-242) and 0.5 to 0.7 μm (EK-3414) (Table 1). Color film density readings were made with four different lights: white (no filter), red (Wratten 92 filter), green (Wratten 93 filter), and blue (Wratten 94 filter). Black-and-white film density readings were made with white light only. Each density reading represents the density of 0.0015 square mm of film, and readings were made at 100 per 2.54 mm on the films.

The various saline areas within the site were located on an isodensitracing (gray map) of each film type. Twelve scan lines were made across the study site on the color film, and 24 scan lines were made on the black-and-white film. (The color film had a larger scale than the black-and-while film because the films were exposed on two different orbits.) Six and nine lines, from bare soil only, for color and black-and-while films, respectively, were randomly selected for use in the ANOV.

Density readings from the saline areas were grouped by scan line, area, color light density, and film type and read into a computer by areas. To eliminate unusually high or low density readings caused by clouds or man-made objects, a mean and standard deviation were calculated, and the computer then eliminated all density readings outside of the interval of the mean ± one standard deviation and then recalculated a mean for each scan line.

The mean density readings for each scan line within each saline area were used as replications for ANOV tests. For the color film, an analysis of variance was calculated for each set of color light densities; one ANOV was calculated for the black-and-white film. The partitioning of degrees of freedom for the color and the black-and-white films is shown in Table 3. The color film had one less saline area than the black-and-white film, because one area (E) was obscured by clouds. Duncan's Multiple Range Test was used to make all possible mean comparisons among saline areas.

Linear correlation analysis relating soil salinity levels to the mean optical densities were calculated for the color and the black-and-white films. Correlations were determined for salinity areas A, B, C, D, F, G, and H (N = 7; Fig. 2) and for salinity areas A, B, C, D, F, and G (N = 6).

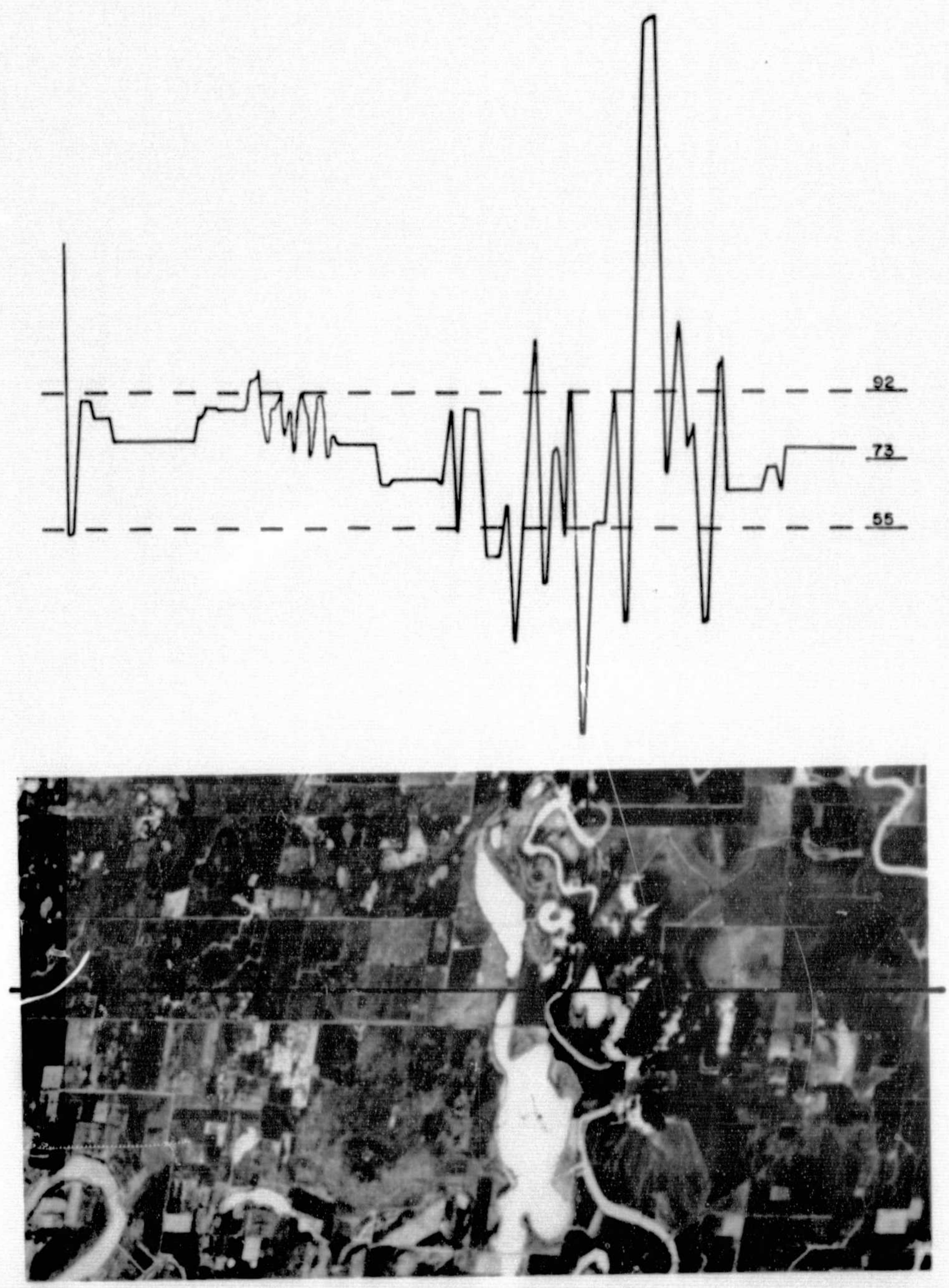



Fig. 3. Isodensitracing of a single scan line through soil, cloud, cloud shadow, and water images along Paredes Road, Cameron County, taken from black-and-white film (EK-3414) illustrating the unusually high or low density readings caused by clouds (dark areas), cloud shadows (white areas), and water (white areas). Editing of these high and low readings was accomplished using standard deviations from the mean and thresholding techniques.

Table 3. Partitioning of degrees of freedom for color and black-and-white films' analysis of variance (ANOV) of soil salinity study in Cameron County.

| ANOV - Source of variation | Color film (0.4 - 0.7 μm) (12/5/73) df | Black-and-white (0.5 - 0.7 μm) (11/29/73) df |
|---|---|---|
| Saline areas | 6 | 7 |
| Replications | 5 | 8 |
| Error | 30 | 56 |
| Total | 41 | 71 |

## Multispectral Scanner Data Collected in Cameron County

Computer compatible digital tapes (CCT) were obtained from four MSS data sources: The December 11, 1973, Mission 258 aircraft overflights (Bendix 24-band MSS) at 1,700 meters (5,700 ft) and 4,800 meters (16,000 ft); the December 11, 1973 LANDSAT-1 overpass (4-band MSS); and the December 5, 1973, SKYLAB overpass (13-band MSS). Threshold values for distinguishing among water, vegetation, and bare soil were determined using band 10 (0.981 to 1.045 μm) for the Bendix 24-band MSS, band 7 (0.78 to 0.88 μm) for the SKYLAB S192 13-band MSS, and MSS 7 (0.8 to 1.1 μm) for the LANDSAT-1 4-band MSS. These bands were selected from visual inspection of MSS digital data displayed on a cathode ray tube, as giving the best contrast between bare soil and vegetation. These threshold values permitted studies of salinity effects on bare soil and vegetation separately and also permitted editing out MSS digital values caused by water. Additional threshold values were determined for the SKYLAB S192 MSS data to permit editing out digital values caused by clouds and cloud shadows.

Line printer gray maps were generated from CCT for each of the four MSS data sources to locate the MSS digital data values on the CCT corresponding to the eight saline study areas. The mean MSS digital data values within each saline area were determined separately for bare soil and vegetation categories. Simple linear correlation analysis was used to relate the $EC_e$ measurements to the mean MSS digital data values from bare soil and vegetation separately for each of the four data sources. Correlation analysis of $EC_e$ measurements was also determined for the digital value difference and ratio between bare soil and vegetation. The rationale was that the reflectance contrast between bare soil and vegetation (i.e., MSS digital value difference or ratio between bare soil and vegetation) should be better indicators of salinity effects than bare soil or vegetation individually. The degrees of freedom for each data source used for correlation analysis are given in Table 4.

Table 4. Degrees of freedom (number of saline areas - 1) for the four multispectral scanner (MSS) data sources used for correlation analysis relating electrical conductivity measurements to four MSS data sources.

| MSS data source | Degrees of freedom | Comments |
|---|---|---|
| Bendix 24-band MSS (1,700 m; 12/11/73) | 7 | Coverage for eight saline areas was complete and cloud-free. |
| Bendix 24-band MSS (4,800 m; 12/11/73) | 5 | Coverage for eight saline areas was incomplete as MSS data for areas G and H were missing. |
| SKYLAB 13-band MSS (12/5/73) | 6 | Coverage for eight saline areas was complete, but area E was covered by clouds. |
| LANDSAT-1 4-band MSS (12/11/73) | 7 | Coverage for eight saline areas was complete and cloud-free. |

## Saline Soil Mapping in Cameron County

A saline soil map was developed using SKYLAB S192 MSS digital data from the MSS band that produced the most reasonable estimated measurements for bare soil areas only. The ECe estimate for the bare soil areas was determined by a linear regression equation derived from bare and vegetated soil MSS differences. Threshold values for SKYLAB were used to distinguish between bare soil and vegetation. Computer line printer symbols were used to represent the ECe estimates for bare soil and also the location of vegetal, cloud, and cloud shadow areas for the saline soil map. The ECe linear regression equation for producing the most reasonable LANDSAT-1 saline soil map was also determined.

# RESULTS

## Starr County Soil Salinity Related to Various Data Sources

A paper entitled "Distinguishing Saline From Non-Saline Rangelands with SKYLAB Imagery" has been prepared by J. H. Everitt, A. H. Gerbermann, and J. A. Cuellar. The results for Starr County taken from this paper follow:

## Ground Truth Data

Table 5 shows the major grasses and woody plants found on the study area and the seven range sites on which they dominate. Botanical composition among these seven sites was similar in many instances, as many of the same grasses and woody plants were dominant on both saline and non-saline range sites. However, a few species such as saladillo (Varilla texana), guapilla (Hechtia glomerata), dwarf screwbean (Prosopis reptans), curly mesquite grass (Hilaria belangeri), and buffalo grass (Buchloe dactyloides) were found only on the saline range sites.

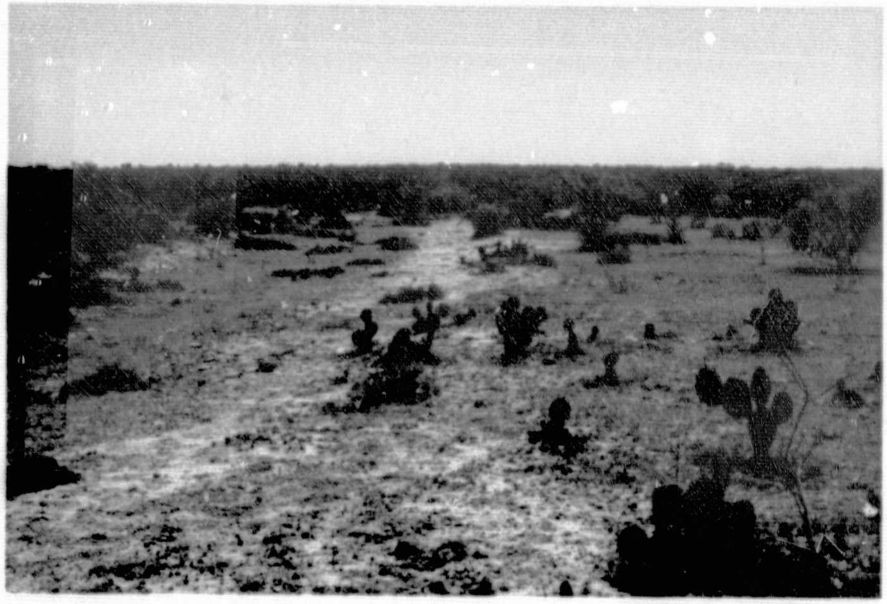
Although many of the same species occur on both saline and non-saline sites, the growth forms and herbage biomass production varies considerably among sites. The grass composition on the saline sites is dominated by shallow-rooted, sod grasses and other short grasses, whereas on the non-saline sites, there is an inter-mixture of short and mid-grass species. The appreciable concentration of soluble salts in the upper soil profiles of the saline range sites limits plant growth (Davis and Spicer, 1965; Fanning et al., 1965). These saline sites are characterized by having large bare soil areas (slicks) and surface deposits of sodium salts (Illus. 1). These conditions lead to appreciably lower amounts of herbaceous biomass on these sites than on the non-saline sites (Fanning et al., 1965; Thompson et al., 1972). The high concentrations of these salts limits the growth form of the woody species to a "stunted" type on saline sites. This is evident when Illus. 1 is compared with Illus. 2. This "stunted" or low brush type is generally comprised of a comparatively low woody plant canopy cover with woody plants less than 1.5 meters (5 ft) tall, whereas on the non-saline range sites, the woody plant canopy covers are more dense with taller and more spreading plants.

Table 5. Major woody plants and grasses found on the seven range sites along a flight line in Starr County, Texas, and the range sites on which they dominate.

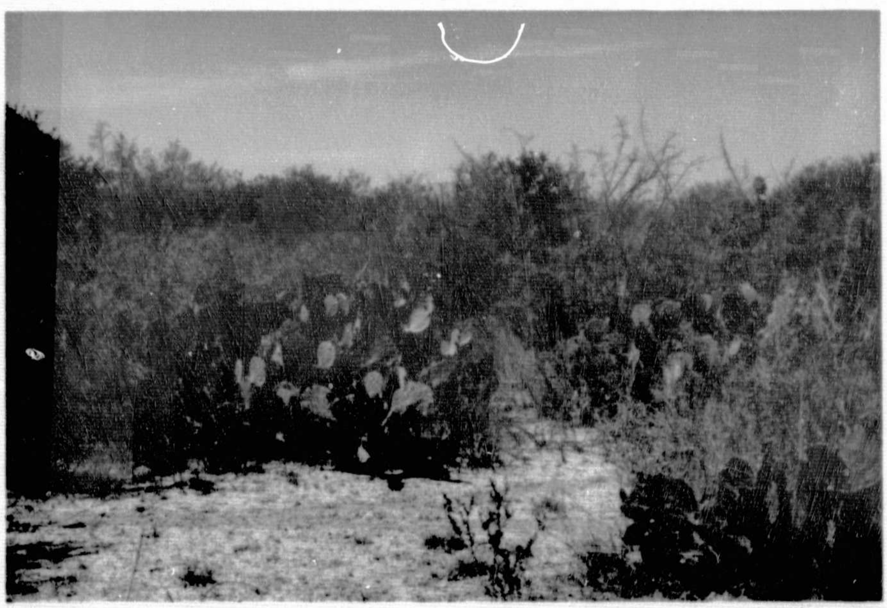
| Species[1] | Site[2] |
|---|---|
| Woody | |
| Acacia berlandieri Benth. | 1,2,4,6,7 |
| A. rigidula Benth. | 1,2,4,5,6,7 |
| Aloysia gratissima (Gill. & Hook.) Troncoso | 3 |
| Castela texana (T. & G.) Rose | 1,2 |
| Celtis pallida Torr. | 5,6 |
| Citharexylum spathulatum Moldenke & Lundell | 5 |
| Eysenhardtia texana Scheele | 6,7 |
| Forestiera angustifolia Torr. | 6 |
| Hechtia glomerata Zucc. | 2 |
| Jatropha dioica Cerv. | 7 |
| Karwinskia humboltiana (R. & S.) Zucc | 7 |
| Krameria ramosissima (Gray) Wats. | 7 |
| Lantana macropoda Torr. | 5 |
| Leucophyllum frutescens (Berl.) I. M. Johnst. | 5,7 |
| Opuntia leptocaulis DC. | 1,3,4,6 |
| O. lindheimeri Engelm. | 3,5 |
| Pithcellobium flexicaule (Benth.) Coult. | 5 |
| Porlieria angustifolia (Engelm.) Gray | 4,5,6 |
| Prosopis glandulosa Torr. | 2,3,4,5,6 |
| P. reptans Benth. | 3 |
| Schaefferia cuneifolia Gray | 5,7 |
| Varilla texana Gray | 1,2,3 |
| Zanthoxylum fagara (L.) Sarg. | 6 |
| Ziziphus obtusifolia (T. & G.) Gray | 1,2,3,4,5 |
| Grasses | |
| Aristida purpurea Nutt. | 1,2,3,4,5,6,7 |
| Bouteloua trifida Thurb. | 1,2,3,4,5,6,7 |
| Buchloe dactyloides (Nutt.) Engelm. | 2,3 |
| Cenchrus ciliaris L. | 4,5,6 |
| Chloris cucullata Bisch. | 5,6,7 |
| Eragrostis curtipedicellata Buckl. | 1,3,5,7 |
| Hilaria belangeri (Steud.) Nash | 1,2,3 |
| Pancium hallii Vasey | 5,6 |
| Setaria texana W.H.P. Emery | 4,5,6,7 |
| Sporobolus cryptandrus (Torr.) Gray | 5,6,7 |
| S. pyramidatus (Lam.) Hitch c. | 1,2,3 |
| Trichloris pluriflora Fourn. | 6 |
| Tridens muticus (Torr.) Nash | 1,4,5,7 |

1 Plant names are according to Correll and Johnston (1970).

2 Site 1 = rolling hardland; Site 2 = saline clay (Catarina soils); Site 3 = saline clay (Montell clay, saline); Site 4 = clay loam; Site 5 = gray sandy loam; Site 6 = Ramadero; Site 7 = shallow ridge.



Illus. 1. Photograph of saline clay range site characterized by having large bare soil areas (slicks) and surface deposits of soluble salts that limit plant growth forms of woody species to a "stunted" type less than 1.5 m (5 ft) tall.



Illus. 2. Photograph of non-saline gray sandy loam range site characterized by dense spreading woody canopy covers over 1.5 m (5 ft) tall.

The $EC_e$ values of the soil extracts from the seven different soil types and their associated range sites are presented in Table 6. These $EC_e$ values relate salt concentration in the soil to the effect on plant growth. Commonly used guides proposed by the United States Salinity Laboratory staff (Richards, 1954) are: salt concentration greater than 4.0 mmhos/cm limits production of most forage crops; above 8.0 mmhos/cm, only moderately salt-tolerant species grow well; and above 12.0 mmhos/cm, only the most salt-tolerant species survive. Based on these guide lines, the two saline clay range sites (Catarina soils and Montella clay, saline) and the rolling hardland range site (Maverick soils, eroded) have $EC_e$ values in the ranges of high salinity. The low $EC_e$ values of the other four range sites (clay loam, gray sandy loam, Ramadero, and shallow ridge) places them in the non-saline category.

Table 6. Microdensitometer readings with white light on SO-022 (0.50 - 0.60 μm), SO-022 (0.60 - 0.70 μm), and EK-2424 (0.70 - 0.80 μm) aerial black-and-white films exposed on the SKYLAB S190A multispectral camera for seven range sites on a flight line in Starr County, Texas. ECe values are expressed in mmhos/cm.

| Range Site | ECe (mmhos/cm) | Film SO-022[1] (0.5 - 0.6 μm) | Film SO-022[1] (0.6 - 0.7 μm) | Film EK-2424[1] (0.7 - 0.8 μm) |
|---|---|---|---|---|
| Rolling hardland (Maverick soils, eroded | 6.4 | 79.64ab | 72.12a | 108.90ab |
| Saline clay (Catarina soils) | 9.4 | 73.40ab | 70.15a | 107.81ab |
| Saline clay (Montell clay, saline) | 12.6 | 84.31a | 68.20ab | 104.01a |
| Clay loam (Garceno clay loam) | 0.9 | 64.38 bc | 63.49 bc | 123.98 c |
| Gray sandy loam (Copita fine sandy loam) | 0.6 | 51.15 c | 60.90 c | 127.31 c |
| Ramadero (Ramadero loam) | 0.6 | 54.58 c | 60.87 c | 124.46 c |
| Shallow ridge (Zapata soils) | 0.6 | 53.22 c | 58.33 c | 120.05 bc |

1 Means followed by a common letter are not significantly different at the 5 percent probability level according to Duncan's Multiple Range Test.

Black-and-white Optical Density Data

Duncan's Multiple Range Test (DMRT) in Table 6 shows statistically significant differences among the seven range sites for mean optical density readings taken with white light on three black-and-white S190A MCF films [SO-022 (0.50 - 0.60 μm), SO-022 (0.60 - 0.70 μm), and EK-2424 (0.70 - 0.80 μm)]. These seven sites were divided into essentially two main groups on each film according to the DMRT. For all films the means followed by the common letter 'a' represent those range sites with the highest salinity and film density, and the means followed by the common letter 'c' were lowest in salinity and film density. However, the DMRT separation between range sites with low and high salinity was not absolute as evidenced by means followed by the common letter 'b'. For the infrared black-and-white film [EK-2424 (0.70 - 0.80 μm)], the means followed by the common letter 'a' represent those range sites with the highest salinity and lowest film density, while those means followed by the common letter 'c' were lowest in salinity and highest in film density. Some overlap between range sites with low and high salinity is evidenced by the means followed by the common letter 'b'.

No significant difference ($P < .05$) was found among mean optical density readings for the seven range sites on infrared S190A MCF black-and-white film [EK-2424 (0.80 - 0.90 μm)]. This film appeared to be over-exposed and therefore the data are not presented.

Saline range sites [saline clay (Catarina soils), saline clay (Montell clay, saline soils), and rolling hardland] could be distinguished from non-saline range sites (gray sandy loam, clay loam, Ramadero, and shallow ridge) with microdensitometry on black-and-white films S190A MCF exposed in the 0.50 - 0.60, 0.60 - 0.70, and 0.70 - 0.80 μm wavelengths. Although complete separation of all saline sites from all non-saline sites could not be accomplished on any of the three black-and-white films (Table 6), the same separation of the seven sites into two main groups was accomplished on all films. Black-and-white film SO-022 (0.60 - 0.70 μm) had the least overlap between range sites with low and high salinity. Here, six absolute separations were achieved among the seven sites. On black-and-white film SO-022 (0.50 - 0.60 μm) and infrared black-and-white film EK 2424 (0.70 - 0.80 μm) four absolute separations were accomplished on each film.

Mean optical density differences among saline and non-saline rangelands were believed to be caused by the high occurrence of bare soil areas on saline range sites. These bare soil areas caused higher optical density readings for saline range sites on black-and-white films exposed in the 0.50 - 0.60 μm and 0.60 - 0.70 μm wavelengths, and lower optical density readings for the black-and-white film exposed in the 0.70 - 0.80 μm wavelength.

## Color Optical Density Data

Table 7 shows statistically significant differences (DMRT) among the seven range sites for mean optical density readings taken with white, red, green, and blue light for color film SO-356 (0.40 - 0.70 μm) and color infrared S190A MCF film EK-2443 (0.50 - 0.88 μm). However, only white light on color film SO-356 showed a partial separation among saline and non-saline range sites. On this film, means followed by the common letter 'a' represent range sites with the highest salinity and lowest film density; means followed by the common letters 'd' and 'e' are non-saline range sites and of higher film density. The mean densities for all other film/filter combinations on color film SO-356 and color infrared film EK-2443 show statistical differences among range sites; however, no definite relationship can be established between film optical densities and range site salinity levels.

The microdensitometer could partially differentiate saline rangelands into one group on color MCF film SO-356 (0.40 - 0.70 μm) with white light (Table 6); however, this was minimal. Other film/filter combinations on color film SO-356 and color infrared film EK-2443 (0.50 - 0.88 μm) showed no definite separation between saline and non-saline range sites.

Mean optical density readings on color and color infrared S190A MCF film showed differences among the various range sites. However, differentiation between saline and non-saline sites was minimal and no definite relationship was found between film optical densities and range site salinity levels. Because differentiation between saline and non-saline range sites on color and color infrared film could not be accomplished, it is believed a film interaction exists, possibly caused by various combinations of soil and vegetation reflectance. Therefore, further study on this interaction is deemed necessary.

Table 7. Microdensitometer readings with white, red, green, and blue lights on SO-356 (0.40 - 0.70 µm) aerial color and EK-2443 (0.50 - 0.88 µm) aerial color infrared films exposed on the SKYLAB S190A multispectral camera for seven range sites on a flight line in Starr County, Texas. ECe values are expressed in mmhos/cm.

| Range site | ECe (mmhos/cm) | SO-356 Color Film (0.40 - 0.70 µm) White light[1] | Red light[1] | Green light[1] | Blue light[1] | EK-2443 Color IR Film (0.50 - 0.88 µm) White light[1] | Red light[1] | Green light[1] | Blue light[1] |
|---|---|---|---|---|---|---|---|---|---|
| Rolling hard-land (Maverick soils, eroded) | 6.4 | 85.09a | 81.88a | 78.74a | 61.48a | 70.89a | 102.66ab | 79.72ab | 47.58ab |
| Saline clay (Catarina soils) | 9.4 | 102.32abc | 93.55ab | 92.39abc | 78.25b | 70.38a | 97.08a | 74.02a | 41.44a |
| Saline clay (Montell clay, saline) | 12.6 | 92.14ab | 87.66ab | 84.34ab | 64.72a | 81.85b | 110.34bc | 88.97bc | 54.36bc |
| Clay loam (Garceno clay loam) | 0.9 | 108.61bcd | 95.18ab | 92.10abc | 78.17b | 81.59b | 112.75bc | 89.81bc | 54.17bc |
| Gray sandy loam (Copita fine sandy loam) | 0.6 | 111.90cde | 105.37bc | 100.06bcd | 82.12bc | 85.89b | 106.83ab | 88.67bc | 60.36cd |
| Ramadero (Ramadero loam) | 0.6 | 129.50e | 118.87c | 109.55d | 91.85c | 82.75b | 111.95bc | 92.27c | 57.90cd |
| Shallow ridge (Zapata soils) | 0.6 | 123.17de | 119.86c | 108.35cd | 85.54bc | 90.84b | 120.60c | 99.04c | 65.34d |

1 Means followed by a common letter are not significantly different at the 5 percent probability level according to Duncan's Multiple Range Test.

## Cameron County Soil Salinity Related to Various Data Sources

Two papers entitled "Detection of Saline Soils in Cameron County, Texas, with SKYLAB Imagery and Multispectral Scanner Data" and "Distinguishing Saline Soil Levels in Cameron County, Texas, with SKYLAB, LANDSAT-1, and Aircraft Multispectral Scanner Data" have both been prepared by A. J. Richardson, A. H. Gerbermann, H. W. Gausman, and J. A. Cuellar. The results for Cameron County taken from these papers follow:

### SKYLAB Optical Density Data

Duncan's Multiple Range Test in Table 8 shows statistically significant differences among saline areas for mean density readings taken with white, red, and green lights for the color film and white light for the black-and-white film (S190B ETC). However, a relation of salinity levels for the saline areas with mean density readings can not be established using the DMRT technique. Examples supporting this reasoning are: (1) areas B, C, and D with respective salinity levels of high, low, and medium were statistically alike for white and red lights with the color film, (2) areas A and B with respective salinity levels of low and high were statistically alike for the green light with color film, (3) all areas were statistically alike for the blue light with color film, and (4) areas E, F, and G with respective salinity levels of low, low, and high were statistically alike for the white light with black-and-white film. As a result of examining the film transparencies, it was found that mean density readings were related to the lightness or darkness of the soils located within the study site.

Linear correlation analysis confirm previous findings that a soil salinity relationship with film optical density measurements can not be established. Correlations between mean density readings (Table 8) and ECe reading (Fig. 2) using salinity areas A, B, C, D, F, G, and H ($N = 7$) were not significant ($r$ ranged from 0.073 to -0.286). Thus a significant relationship between saline effects and film optical densities (S190B ETC) can not be established using either DMRT or correlation analysis.

Table 8. Duncan's Multiple Range Test among saline soil areas using microdensitometer readings with white, red, green, and blue light on SO-242 aerial color and white light on EK-3414 black-and-white films exposed in the Earth Terrain Camera (S190B). Means followed by a common letter are not significantly different at the 5 percent probability level. Linear correlation coefficients relating salinity measurements to means are also given.

| Saline area | Relative salinity level | Color film (12/5/73) White light | Color film (12/5/73) Red light | Color film (12/5/73) Green light | Color film (12/5/73) Blue light | Black-and-white film (11/29/73) White light |
|---|---|---|---|---|---|---|
| | | Means | | | | |
| A | Low | 57a | 72a | 57ab | 46a | 77a |
| B | High | 51 b | 68 b | 58 b | 43a | 80a |
| C | Low | 54 b | 63 b | 51 c | 46a | 75 b |
| D | Medium | 48 b | 62 b | 51 c | 47a | 64 c |
| E | Low | -- | -- | -- | -- | 78a |
| F | Low | 57a | 75a | 57ab | 48a | 78a |
| G | High | 53 b | 71a | 56ab | 49a | 80a |
| H | Medium | 46 b | 63 b | 46 c | 43a | 76 b |
| | | Correlation (r) | | | | |
| Saline areas A, B, C, D, F, G, and H related with: | | -0.286 | 0.073 | 0.172 | 0.248 | 0.241 |

## Aircraft Multispectral Scanner Data

Multispectral scanner threshold values (digital data) for distinguishing among water, vegetation, and bare soil using Bendix 24-band MSS data at 1,700 m and 4,800 m, from MSS band 10 (0.981 to 1.045 μm), are given as follows:

| | 1,700 m | 4,800 m |
|---|---|---|
| Water | 38 - 49 | 34 - 39 |
| Vegetation | 50 - 79 | 40 - 59 |
| Bare Soil | 80 - 122 | 60 - 94 |

These threshold values were used to determine the Bendix 24-band MSS digital mean data for bare soil and vegetation categories individually for the eight saline soil areas (Fig. 2) in Cameron County at 1,700 m (Table 9) and 4,800 m (Table 10). Electrical conductivity measurements used for correlation analysis are also given in Tables 9 and 10.

Linear correlation analysis showed that there was no significant difference between correlations of Bendix 24-band MSS digital data collected at 1,700 m and at 4,800 m to ECe measurements. Correlation coefficients (Table 11) ranging from 0.045 to -0.853** for MSS data collected at 1,700 m and ranging from 0.0 to -0.862** for MSS data collected at 4,800 m, considering bare soil (BS), vegetation (VEG), VEG-BS, and VEG/BS, support this conclusion.

Multispectral scanner data collected at 1,700 m was correlated highest with ECe measurements for the difference between vegetation and bare soil (r = -0.853**; 1.133 to 1.17 μm) as compared with bare soil (r = 0.827**; 0.82 to 0.88 μm), vegetation (r = -0.826**; 1.133 to 1.17 μm), and the ratio of vegetation and bare soil (r = -0.841**; 1.133 to 1.117 μm). At 4,800 m the ratio of vegetation and bare soil was correlated highest (r = -0.862**; 0.72 to 0.76 μm) with ECe measurements. These results show that a measure of the vegetation and bare soil contrast, in the infrared spectral region (0.72 to 1.17 μm), is the best indicator of saline soil effects, as compared with vegetation and bare soil individually, at aircraft altitudes.

TABLE 9 BENDIX 24-BAND MULTISPECTRAL SCANNER (MSS) DIGITAL MEAN DATA AND ELECTRICAL CONDUCTIVITY ($EC_e$) READINGS FOR SALINE AREAS STUDIED IN CAMERON COUNTY. DATA WERE COLLECTED ON DECEMBER 11,1973 AT 1,700 M. THESE DATA WERE USED FOR CORRELATION ANALYSIS RELATING MSS DATA, FOR EACH BAND, TO $EC_e$ READINGS IN MMHOS/CM.

| MSS BAND | WAVELENGTH INTERVAL IN MICRO-METERS | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR VEGETATION. | | | | | | | | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR BARE SOIL. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H |
| 1 | 0.375-0.405 | 51 | 51 | 61 | 53 | 49 | 49 | 50 | 51 | 50 | 52 | 56 | 51 | 51 | 51 | 59 | 52 |
| 2 | 0.40 -0.44 | 53 | 52 | 64 | 53 | 50 | 51 | 54 | 53 | 52 | 54 | 59 | 53 | 52 | 53 | 63 | 54 |
| 3 | 0.466-0.495 | 60 | 58 | 69 | 59 | 57 | 56 | 56 | 55 | 56 | 58 | 62 | 58 | 59 | 54 | 66 | 57 |
| 4 | 0.53 -0.58 | 76 | 69 | 83 | 71 | 69 | 66 | 50 | 66 | 59 | 64 | 68 | 67 | 66 | 64 | 45 | 57 |
| 5 | 0.588-0.643 | 61 | 57 | 67 | 55 | 55 | 52 | 62 | 57 | 50 | 52 | 57 | 54 | 54 | 51 | 68 | 57 |
| 6 | 0.65 -0.69 | 74 | 70 | 82 | 65 | 66 | 61 | 62 | 67 | 60 | 62 | 70 | 64 | 66 | 61 | 60 | 60 |
| 7 | 0.72 -0.76 | 91 | 77 | 83 | 84 | 81 | 79 | 82 | 77 | 52 | 60 | 60 | 65 | 65 | 62 | 74 | 70 |
| 8 | 0.77 -0.81 | 112 | 95 | 100 | 105 | 100 | 100 | 90 | 91 | 60 | 72 | 70 | 78 | 78 | 74 | 74 | 78 |
| 9 | 0.82 -0.88 | 106 | 92 | 97 | 99 | 95 | 95 | 128 | 96 | 58 | 68 | 68 | 74 | 75 | 70 | 136 | 100 |
| 10 | 0.981-1.045 | 97 | 88 | 91 | 91 | 90 | 87 | 85 | 83 | 57 | 65 | 66 | 70 | 72 | 66 | 69 | 69 |
| 11 | 1.2 -1.3 | 84 | 78 | 84 | 78 | 80 | 74 | 82 | 71 | 58 | 62 | 64 | 65 | 68 | 61 | 80 | 69 |
| 12 | 1.533-1.62 | 54 | 55 | 61 | 50 | 55 | 48 | 36 | 44 | 47 | 48 | 49 | 48 | 52 | 44 | 32 | 38 |
| 13 | 2.3 -2.43 | 58 | 51 | 64 | 49 | 53 | 51 | 117 | 86 | 59 | 51 | 60 | 53 | 56 | 52 | 136 | 90 |
| 14 | 3.78 -4.04 | 250 | 254 | 255 | 255 | 253 | 255 | 252 | 253 | 251 | 252 | 255 | 255 | 255 | 255 | 255 | 253 |
| 15 | 4.5 -4.76 | 106 | 109 | 120 | 99 | 98 | 90 | 81 | 88 | 118 | 108 | 118 | 103 | 103 | 101 | 93 | 82 |
| 16 | 6.0 -7.0 | 103 | 92 | 115 | 95 | 88 | 85 | 53 | 71 | 105 | 96 | 104 | 92 | 91 | 90 | 56 | 67 |
| 17 | 8.27 -8.7 | 194 | 195 | 221 | 178 | 174 | 162 | 156 | 175 | 203 | 198 | 225 | 183 | 181 | 181 | 184 | 161 |
| 18 | 8.8 -9.3 | 212 | 212 | 242 | 197 | 191 | 180 | 206 | 198 | 215 | 216 | 245 | 199 | 197 | 199 | 247 | 198 |
| 19 | 9.38 -9.876 | 215 | 216 | 247 | 202 | 196 | 184 | 109 | 169 | 225 | 218 | 247 | 204 | 205 | 203 | 126 | 153 |
| 20 | 10.9 -11.0 | 192 | 192 | 223 | 180 | 174 | 165 | 194 | 177 | 211 | 199 | 225 | 187 | 183 | 189 | 239 | 187 |
| 21 | 11.1 -12.0 | 185 | 185 | 216 | 177 | 170 | 160 | 119 | 178 | 204 | 193 | 216 | 181 | 179 | 178 | 153 | 148 |
| 22 | 12.0 -13.0 | 174 | 172 | 201 | 165 | 160 | 149 | 143 | 168 | 191 | 178 | 199 | 168 | 170 | 165 | 186 | 160 |
| 23 | 1.133-1.17 | 62 | 60 | 70 | 62 | 61 | 60 | 40 | 51 | 55 | 56 | 60 | 56 | 58 | 57 | 56 | 45 |
| 24 | 1.06 -1.095 | 88 | 78 | 83 | 84 | 84 | 78 | 77 | 69 | 52 | 59 | 58 | 64 | 66 | 60 | 66 | 61 |
| ELECTRICAL CONDUCTIVITY READINGS | MMHOS/CM | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 |

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TABLE 10 BENDIX 24-BAND MULTISPECTRAL SCANNER (MSS) DIGITAL MEAN DATA AND ELECTRICAL CONDUCTIVITY ($EC_e$) READINGS FOR SALINE AREAS STUDIED IN CAMERON COUNTY. DATA WERE COLLECTED ON DECEMBER 11,1973 AT 4,800 M. THESE DATA WERE USED FOR CORRELATION ANALYSIS RELATING MSS DATA, FOR EACH BAND, TO $EC_e$ READINGS IN MMHOS/CM.

| MSS BAND | WAVELENGTH INTERVAL IN MICRO METERS | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR VEGETATION | | | | | | | | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR BARE SOIL | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H |
| 1 | 0.375-0.405 | 60 | 58 | 57 | 57 | 58 | 64 | - | - | 57 | 58 | 57 | 57 | 58 | 60 | - | - |
| 2 | 0.40 -0.44 | 74 | 71 | 69 | 70 | 70 | 76 | - | - | 70 | 71 | 70 | 70 | 71 | 69 | - | - |
| 3 | 0.466-0.495 | 66 | 63 | 62 | 63 | 63 | 69 | - | - | 62 | 63 | 60 | 61 | 63 | 63 | - | - |
| 4 | 0.53 -0.58 | 80 | 76 | 72 | 76 | 77 | 77 | - | - | 69 | 71 | 68 | 71 | 74 | 70 | - | - |
| 5 | 0.588-0.643 | 63 | 60 | 56 | 59 | 60 | 61 | - | - | 55 | 56 | 55 | 56 | 57 | 55 | - | - |
| 6 | 0.65 -0.69 | 67 | 65 | 60 | 62 | 64 | 73 | - | - | 59 | 60 | 59 | 58 | 61 | 62 | - | - |
| 7 | 0.72 -0.76 | 63 | 63 | 62 | 64 | 67 | 65 | - | - | 50 | 52 | 49 | 54 | 52 | 51 | - | - |
| 8 | 0.77 -0.81 | 70 | 71 | 71 | 73 | 77 | 78 | - | - | 54 | 57 | 53 | 60 | 57 | 58 | - | - |
| 9 | 0.82 -0.88 | 60 | 61 | 62 | 63 | 66 | 70 | - | - | 46 | 49 | 45 | 50 | 48 | 49 | - | - |
| 10 | 0.981-1.045 | 65 | 66 | 65 | 65 | 69 | 73 | - | - | 51 | 53 | 50 | 54 | 52 | 51 | - | - |
| 11 | 1.2 -1.3 | 60 | 61 | 60 | 59 | 63 | 66 | - | - | 51 | 51 | 49 | 50 | 49 | 47 | - | - |
| 12 | 1.533-1.62 | 55 | 52 | 50 | 47 | 51 | 53 | - | - | 49 | 48 | 45 | 42 | 44 | 37 | - | - |
| 13 | 2.3 -2.43 | 58 | 53 | 52 | 50 | 53 | 58 | - | - | 59 | 53 | 53 | 48 | 51 | 43 | - | - |
| 14 | 3.78 -4.04 | 252 | 253 | 253 | 253 | 253 | 253 | - | - | 254 | 253 | 253 | 253 | 253 | 254 | - | - |
| 15 | 4.5 -4.76 | 77 | 77 | 76 | 72 | 71 | 67 | - | - | 80 | 81 | 81 | 72 | 72 | 59 | - | - |
| 16 | 6.0 -7.0 | 2 | 0 | 1 | 1 | 0 | 1 | - | - | 0 | 0 | 0 | 0 | 0 | 0 | - | - |
| 17 | 8.27 -8.7 | 143 | 154 | 155 | 146 | 145 | 141 | - | - | 154 | 167 | 166 | 141 | 146 | 118 | - | - |
| 18 | 8.8 -9.3 | 164 | 178 | 176 | 169 | 166 | 165 | - | - | 175 | 188 | 188 | 165 | 168 | 141 | - | - |
| 19 | 9.38 -9.876 | 173 | 181 | 180 | 171 | 170 | 165 | - | - | 183 | 191 | 191 | 166 | 171 | 139 | - | - |
| 20 | 10.5 -11.0 | 152 | 150 | 156 | 154 | 151 | 160 | - | - | 162 | 162 | 156 | 178 | 156 | 195 | - | - |
| 21 | 11.1 -12.0 | 152 | 148 | 152 | 143 | 145 | 142 | - | - | 160 | 160 | 162 | 140 | 150 | 124 | - | - |
| 22 | 12.0 -13.0 | 140 | 137 | 141 | 132 | 134 | 126 | - | - | 147 | 147 | 148 | 128 | 137 | 113 | - | - |
| 23 | 1.133-1.17 | 48 | 48 | 47 | 47 | 46 | 47 | - | - | 44 | 45 | 44 | 43 | 44 | 41 | - | - |
| 24 | 1.06 -1.095 | 71 | 71 | 71 | 71 | 77 | 66 | - | - | 54 | 55 | 52 | 58 | 56 | 45 | - | - |
| ELECTRICAL CONDUCTIVITY READINGS | MMHOS/CM | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 |

TABLE 11 LINEAR CORRELATION ANALYSIS RELATING SOIL SALINITY LEVELS(ELECTRICAL CONDUCTIVITY READINGS) TO EACH OF BARE SOIL (BS), VEGETATION (VEG), VEG-BS, AND VEG/BS BENDIX 24-BAND MSS DIGITAL DATA. DATA WERE COLLECTED FROM PAREDES LINE ROAD AND FARM ROAD 510 ON DECEMBER 11, 1973 FROM EIGHT SALINE SOIL AREAS AT 1,700 M. AND 4,800 M.

| BENDIX MSS BANDS | SALINITY AREAS A THROUGH H CORRELATED WITH (N=8; 1,737 M): | | | | SALINITY AREAS A THROUGH F CORRELATED WITH (N=6; 4,877 M): | | | |
|---|---|---|---|---|---|---|---|---|
| | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS |
| 1 | 0.671** | -0.241 | -0.747** | -0.721** | -0.067 | -0.303 | -0.401 | -0.406 |
| 2 | 0.686** | -0.106 | -0.805** | -0.781** | 0.357 | -0.210 | -0.258 | -0.250 |
| 3 | 0.656** | -0.296 | -0.779** | -0.759** | 0.156 | -0.290 | -0.415 | -0.421 |
| 4 | -0.769** | -0.815** | -0.331 | -0.219 | 0.155 | -0.077 | -0.183 | -0.178 |
| 5 | 0.778** | 0.132 | -0.679** | -0.635 | 0.255 | -0.042 | -0.123 | -0.107 |
| 6 | -0.437 | -0.437 | -0.260 | -0.246 | -0.267 | -0.140 | -0.067 | -0.029 |
| 7 | 0.664** | -0.233 | -0.555* | -0.528* | 0.627* | -0.247 | -0.828** | -0.862** |
| 8 | 0.225 | -0.635** | -0.503* | -0.455 | 0.526 | -0.296 | -0.790** | -0.851** |
| 9 | 0.827** | 0.728** | -0.684** | -0.621* | 0.645* | -0.314 | -0.706* | -0.812** |
| 10 | 0.258 | -0.617* | -0.487 | -0.444 | 0.787** | -0.291 | -0.549 | -0.616* |
| 11 | 0.763** | 0.015 | -0.620* | -0.603* | 0.487 | -0.308 | -0.394 | -0.411 |
| 12 | -0.750** | -0.748** | -0.269 | -0.077 | 0.180 | -0.334 | -0.382 | -0.371 |
| 13 | 0.790** | 0.740** | -0.850** | -0.697** | -0.088 | -0.443 | -0.160 | -0.253 |
| 14 | 0.528* | -0.300 | -0.706** | -0.680** | -0.418 | 0.316 | 0.413 | 0.411 |
| 15 | -0.464 | -0.531* | -0.158 | -0.221 | 0.210 | 0.252 | -0.166 | -0.167 |
| 16 | -0.747** | -0.753** | -0.257 | -0.337 | 0.000 | -0.413 | -0.413 | -0.000 |
| 17 | -0.241 | -0.465 | -0.414 | -0.404 | 0.254 | 0.403 | -0.167 | -0.159 |
| 18 | 0.462 | -0.013 | -0.711** | -0.654** | 0.268 | 0.572 | -0.098 | -0.086 |
| 19 | -0.740** | -0.758** | -0.174 | -0.360 | 0.210 | 0.396 | -0.120 | -0.118 |
| 20 | 0.510* | 0.077 | -0.657** | -0.580* | 0.013 | -0.379 | -0.142 | -0.167 |
| 21 | -0.565* | -0.719** | -0.354 | -0.397 | 0.058 | -0.220 | -0.163 | -0.168 |
| 22 | 0.045 | -0.508* | -0.615* | -0.591* | 0.072 | -0.072 | -0.162 | -0.168 |
| 23 | -0.139 | -0.826** | -0.853** | -0.841** | 0.301 | 0.096 | -0.331 | -0.325 |
| 24 | 0.471 | -0.411 | -0.541* | -0.519* | 0.391 | -0.124 | -0.707* | -0.644* |

* SIGNIFICANT AT THE 5% PROBABILITY LEVEL.
** SIGNIFICANT AT THE 1% PROBABILITY LEVEL.

Satellite Multispectral Scanner Data

Multispectral scanner threshold values (digital data) for distinguishing among cloud shadow, water, vegetation, bare soil, and clouds using SKYLAB and LANDSAT-1 MSS data, from MSS bands 7 (0.78 to 0.88 μm) and (0.8 to 1.1 μm), respectively, are given as follows:

| | SKYLAB | LANDSAT-1 |
|---|---|---|
| Cloud Shadow | 10 - 20 | - - |
| Water | 4 - 20 | 0 - 4 |
| Bare Soil | 21 - 39 | 5 - 10 |
| Vegetation | 40 - 72 | 11 - 20 |
| Cloud | 73 - 181 | - - |

These threshold values were used to determine the satellite MSS digital mean data for bare soil and vegetation categories (Table 12) for the eight saline soil areas (Fig. 2) in Cameron County. Electrical conductivity measurements used for correlation analysis are listed in Table 12 as well as Fig. 2 for convenience.

Initially, correlation analysis showed that SKYLAB S192 and LANDSAT-1 MSS mean digital values were not very well correlated with ECe measurements as compared to the Bendix 24-band MSS data. Correlation coefficients (Table 13) ranging from 0.029 to -0.656**, for S192 MSS data (N = 7), and 0.075 to -0.568** for LANDSAT-I MSS data (N = 8), show that even though some of these correlations were significant, they were too small to be conclusive. Using graphical methods it was found that saline area H, in SKYLAB S192 MSS data, and saline area G, in LANDSAT-1 MSS data, deviated significantly from a linear relationship with ECe measurements. These areas were deleted from the analysis, and new correlation coefficients were determined.

The new correlation coefficients (Table 13) show that the SKYLAB S192 MSS data (bands 6 to 11) and LANDSAT-1 MSS data (bands 6 and 7) are highly correlated with the ECe measurements. Maximum correlation coefficients of -0.963**, for SKYLAB S192 MSS data (N = 6), and of -0.859**, for LANDSAT-1 MSS data (N = 7), considering bare soil (BS), vegetation (VEG), VEG-BS, and VEG/BS, support this conclusion.

Highest correlations were found using the difference between readings from vegetation and bare soil, for both SKYLAB S192 MSS data (r = -0.963**, 1.2 to 1.3 μm) and LANDSAT-1 MSS data (r = -0.859**; 0.8 to 1.1 μm); as compared with bare soil, vegetation, or the ratio of vegetation and bare soil data. These results show that a measure of the contrast between vegetation and bare soil, in the infrared spectral region (0.8 to 1.3 μm), is the best indicator of saline soil effects, as compared to vegetation and bare soil individually, at satellite altitudes.

TABLE 12 SKYLAB 13-BAND MULTISPECTRAL SCANNER(MSS) AND LANDSAT-1 4-BAND MSS MEAN DIGITAL DATA AND ELECTRICAL CONDUCTIVITY ($EC_e$) READINGS FOR SALINE AREAS STUDIED IN CAMERON COUNTY. DATA WERE COLLECTED ON DECEMBER 5, 1973 FOR SKYLAB MSS DATA AND DECEMBER 11, 1973 FOR LANDSAT-1 MSS DATA. THESE DATA WERE USED FOR CORRELATION ANALYSIS RELATING MSS DATA TO EC READINGS IN MMHOS/CM.



| MSS BAND | WAVELENGTH INTERVAL IN MICROMETERS | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR VEGETATION. | | | | | | | | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR BARE SOIL. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H |
| 1 | 0.41 -0.46 | 48 | 51 | 57 | 52 | - | 50 | 47 | 49 | 48 | 47 | 51 | 50 | - | 47 | 47 | 49 |
| 2 | 0.46 -0.51 | 85 | 94 | 98 | 86 | - | 88 | 84 | 86 | 83 | 85 | 81 | 80 | - | 83 | 85 | 89 |
| 3 | 0.52 -0.55 | 47 | 50 | 51 | 49 | - | 45 | 45 | 48 | 43 | 45 | 42 | 43 | - | 43 | 44 | 48 |
| 4 | 0.56 -0.61 | 27 | 34 | 33 | 31 | - | 27 | 25 | 27 | 24 | 29 | 25 | 25 | - | 24 | 23 | 27 |
| 5 | 0.62 -0.67 | 33 | 37 | 42 | 37 | - | 31 | 30 | 34 | 30 | 31 | 33 | 33 | - | 29 | 29 | 31 |
| 6 | 0.69 -0.76 | 60 | 57 | 60 | 59 | - | 53 | 52 | 55 | 44 | 46 | 43 | 44 | - | 41 | 41 | 51 |
| 7 | 0.78 -0.88 | 48 | 47 | 48 | 48 | - | 48 | 44 | 44 | 29 | 31 | 30 | 31 | - | 30 | 29 | 37 |
| 8 | 0.98 -1.08 | 60 | 65 | 61 | 59 | - | 58 | 56 | 53 | 38 | 46 | 39 | 39 | - | 39 | 38 | 49 |
| 9 | 1.09 -1.19 | 63 | 60 | 63 | 61 | - | 68 | 63 | 55 | 43 | 44 | 42 | 43 | - | 42 | 51 | 52 |
| 10 | 1.2 -1.3 | 64 | 62 | 63 | 58 | - | 61 | 58 | 56 | 44 | 45 | 42 | 40 | - | 42 | 43 | 55 |
| 11 | 1.55 -1.75 | 51 | 51 | 52 | 44 | - | 47 | 43 | 42 | 44 | 42 | 40 | 35 | - | 39 | 42 | 43 |
| 12 | 2.1 -2.35 | 37 | 39 | 43 | 33 | - | 36 | 31 | 31 | 40 | 35 | 36 | 30 | - | 34 | 38 | 36 |
| 13 | 10.2 -12.5 | 130 | 137 | 133 | 128 | - | 141 | 131 | 130 | 133 | 135 | 134 | 130 | - | 135 | 136 | 134 |

| MSS BAND | WAVELENGTH INTERVAL IN MICROMETERS | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR VEGETATION. | | | | | | | | MSS AND $EC_e$ DATA FROM SALINE AREAS FOR BARE SOIL. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | A | B | C | D | E | F | G | H |
| 4 | 0.5 -0.6 | 235 | 236 | 231 | 230 | 231 | 223 | 238 | 246 | 220 | 226 | 212 | 220 | 225 | 217 | 227 | 243 |
| 5 | 0.6 -0.7 | 204 | 204 | 193 | 187 | 197 | 181 | 209 | 208 | 185 | 190 | 173 | 176 | 187 | 178 | 193 | 203 |
| 6 | 0.7 -0.8 | 268 | 249 | 256 | 256 | 275 | 244 | 254 | 260 | 171 | 185 | 160 | 202 | 187 | 169 | 173 | 216 |
| 7 | 0.8 -1.1 | 280 | [illegible] | 266 | 258 | 282 | 252 | 254 | 254 | 154 | 166 | 142 | 180 | 162 | 150 | 158 | 184 |
| ELECTRICAL CONDUCTIVITY READINGS | MMHOS/CM | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 | 1.9 | 20.1 | 1.6 | 13.9 | 1.3 | 3.6 | 40.9 | 11.8 |

TABLE 13 SIMPLE LINEAR CORRELATION ANALYSIS RELATING SOIL SALINITY LEVELS (ELECTRICAL CONDUCTIVITY READINGS) TO EACH OF BARE SOIL (BS), VEGETATION (VEG), VEG-BS, AND VEG/BS MSS DIGITAL DATA. DATA WERE COLLECTED FROM PAREDES LINE ROAD AND FARM ROAD 510 ON THE DECEMBER 5, 1973 SKYLAB OVERPASS FROM SEVEN SALINE SOIL AREAS AND DECEMBER 11, 1973 LANDSAT-1 OVERPASS FROM EIGHT SALINE SOIL AREAS.

| S192 MSS BAND NUMBER | SALINITY AREAS A,B,C,D,F,G,AND H CORRELATED WITH (N=7): | | | | SALINITY AREAS A,B,C,D,F,AND G CORRELATED WITH (N=6): | | | |
|---|---|---|---|---|---|---|---|---|
| | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS |
| 1 | -0.437 | -0.448 | -0.307 | -0.294 | -0.438 | -0.481 | -0.389 | -0.376 |
| 2 | 0.327 | -0.355 | -0.428 | -0.434 | 0.588* | -0.375 | -0.527 | -0.530 |
| 3 | 0.153 | -0.357 | -0.362 | -0.370 | 0.430 | -0.358 | -0.456 | -0.462 |
| 4 | 0.055 | -0.250 | -0.367 | -0.396 | 0.078 | -0.272 | -0.505 | -0.543 |
| 5 | -0.357 | -0.435 | -0.463 | -0.475 | -0.354 | -0.445 | -0.492 | -0.507 |
| 6 | -0.110 | -0.597* | -0.340 | -0.312 | -0.136 | -0.623* | -0.739** | -0.727** |
| 7 | 0.000 | -0.656** | -0.293 | -0.275 | 0.162 | -0.929** | -0.946** | -0.865** |
| 8 | 0.062 | -0.259 | -0.198 | -0.213 | 0.159 | -0.393 | -0.862** | -0.688* |
| 9 | 0.670** | -0.116 | -0.455 | -0.525 | 0.936** | -0.258 | -0.876** | -0.905** |
| 10 | 0.029 | -0.548* | -0.277 | -0.278 | 0.184 | -0.760** | -0.963** | -0.869** |
| 11 | 0.064 | -0.504 | -0.499 | -0.479 | 0.083 | -0.626* | -0.722** | -0.680* |
| 12 | 0.050 | -0.567* | -0.513 | -0.503 | 0.051 | -0.649* | -0.569 | -0.566 |
| 13 | 0.420 | -0.157 | -0.374 | -0.368 | 0.424 | -0.180 | -0.423 | -0.416 |

| LANDSAT-1 BAND NUMBER | SALINITY AREAS A THROUGH H CORRELATED WITH (N=8): | | | | SALINITY AREAS A,B,C,D,E,F, AND H CORRELATED WITH (N=7): | | | |
|---|---|---|---|---|---|---|---|---|
| | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS | BARE SOIL (BS) | VEGETATION (VEG) | VEG-BS | VEG/BS |
| 4 | 0.345 | 0.414 | -0.075 | -0.096 | 0.397 | 0.441 | -0.280 | -0.292 |
| 5 | 0.437 | 0.501 | 0.126 | 0.078 | 0.268 | 0.368 | -0.170 | -0.183 |
| 6 | -0.192 | -0.355 | -0.365 | -0.324 | -0.445 | 0.385* | -0.780** | -0.749** |
| 7 | -0.245 | -0.568* | -0.496 | -0.431 | -0.730** | 0.674** | -0.859** | -0.835* |

* SIGNIFICANT AT THE 5% PROBABILITY LEVEL.
** SIGNIFICANT AT THE 1% PROBABILITY LEVEL.

Saline Soil Mapping with SKYLAB and LANDSAT-1 Multispectral Scanner Data

Figure 4 presents the saline soil map for three of the eight saline soil areas (A, B, and C) in Cameron County using S192 digital data, from band 7, to estimate electrical conductivity measurements for bare soil areas with computer line printer symbols defined as follows: 0 to 4 mmhos/cm (.), 5 to 8 mmhos/cm (-), 9 to 12 mmhos/cm (/), 13 to 20 mmhos/cm (+), 21 to 28 mmhos/cm (0), and 29 to 40 mmhos/cm (I). Vegetal, cloud, and cloud shadow regions are printed as the computer line printer symbol "x", space, and "*", respectively. Each symbol represents approximately 0.40 ha (1 acre).

Column A (Fig. 4) is a CCT record count while columns VEG and BS are the average digital value, from S192 band 9, calculated for vegetation and bare soil, respectively, for each record. The average estimated electrical conductivity (ECe) for each record is determined from the column for VEG and for BS using the equation:

$$ECe = 68.5 + 2.9\ (BS - VEG).$$

The equation for estimating ECe is very sensitive to changes in bare and vegetated soil digital value differences; a small change in digital value difference causes a large change in the estimated ECe. Therefore, the estimated ECe from CCT record ranges from a minimum of -33.6 mmhos/cm to a maximum of 47.6 mmhos/cm (Fig. 4). In general, Fig. 4 shows that the estimated ECe's for area A (between CCT records 261 to 296; 9.1 mmhos/cm) and area C (between CCT records 329 to 359; 14.0 mmhos/cm) are lower than for area B (between CCT records 297 to 328; 25.0 mmhos/cm). Thus, these results indicate that the saline soil map relates fairly well to areas where low and high ECe measurements were found.

Studies using LANDSAT-1 DC values produced a more stable relation to bare- and vegetated-soil differences from MSS band 9 as expressed by:

$$ECe = 40.1 + 5.5\ (BS - VEG).$$

In the limiting condition of no difference between bare and vegetated soil (BS - VEG = 0), the estimated ECe = 40.1 mmhos/cm for the LANDSAT-1 is much closer to the upper limit of electrical conductivities measured for the soil than the ECe = 68.5 for the S192 data equation. Soil salinities corresponding to electrical conductivities >40 mmhos/cm permit growth only of halophytes.

Path radiance of surrounding materials may influence the ECe estimates determined for the saline soil map (Malila et al., 1971). Most "I" signs (high salinity) appear in areas, such as between records 297 to 328 (Fig. 4), where bare soil is surrounded by large areas of vegetations (x's). The contrast of bare and vegetated soil may be decreased by the scattering of vegetal path radiance into the optical path, sensed by the S192 MSS, of nearby bare soil. Therefore, high salinity estimates appear to result where large areas of native vegetation are adjacent to bare soil areas.

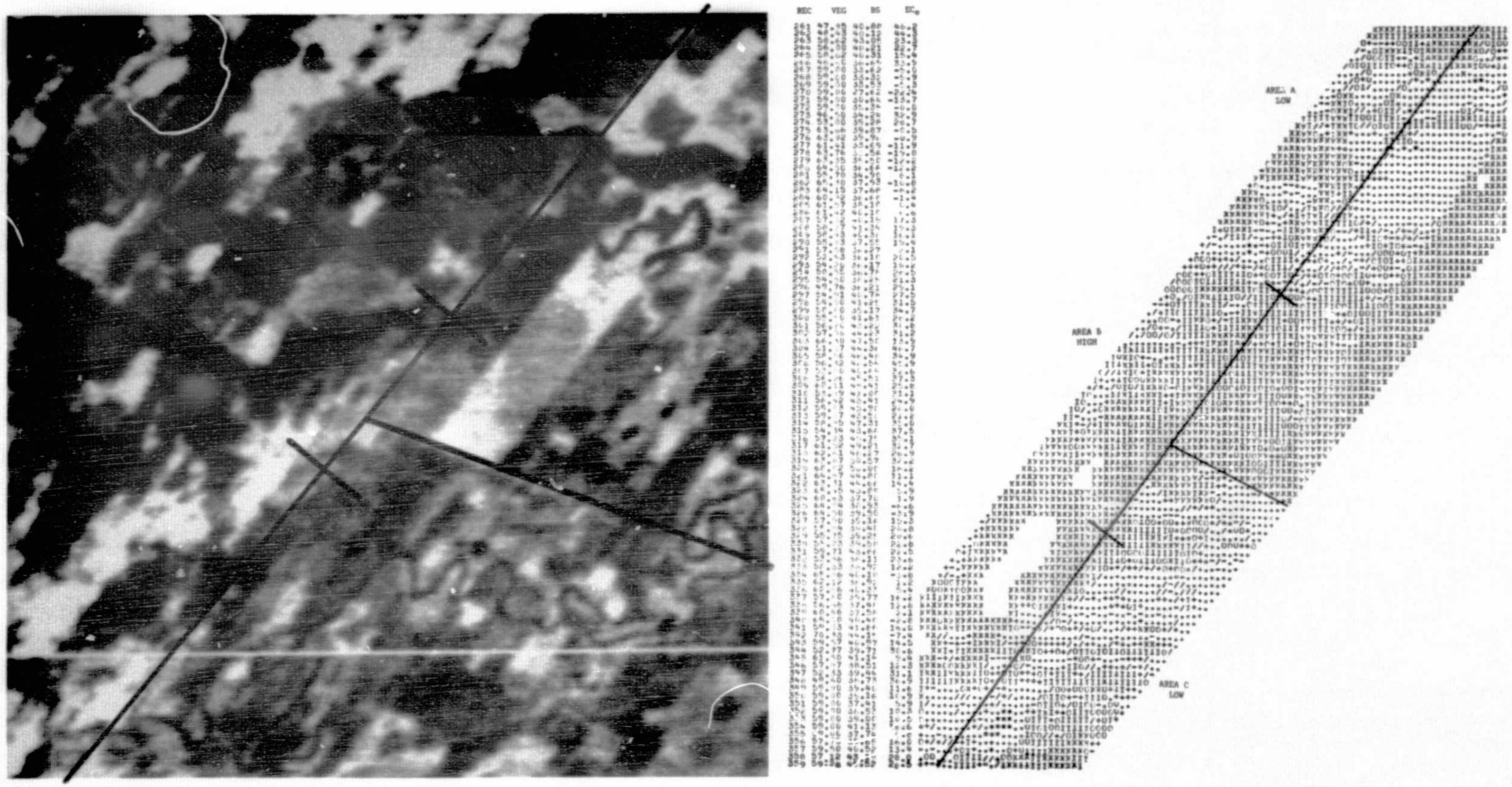


Fig. 4. Gray scale imagery and computer line printer saline soil map for three of eight saline soil areas (A, B, and C) in Cameron County using SKYLAB S192 digital data from band 9 (December 5, 1973). The saline soil map was generated by estimating ECe measurements for bare soil areas only. Vegetal, cloud, and cloud shadow areas appear as the line printer symbols x, space, and *; symbols for electrical conductivity are defined as follows: 0 to 4 mmhos/cm (.), 5 to 8 mmhos/cm (-), 9 to 12 mmhos/cm (/), 13 to 20 mmhos/cm (+), 21 to 28 mmhos/cm (0), and 29 to 40 mmhos/cm (I). Column REC is a record counter. Column VEG and BS are the average digital values calculated for vegetation and bare soil, respectively. Column ECe is the estimated electrical conductivity, in mmhos/cm, calculated for each record using the equation ECe = 68.5 + 2.9 (BS - VEG).

## SIGNIFICANT RESULTS

Growth forms and herbage biomass production varied considerably among saline and non-saline soil range sites in Starr County. Grasses on saline soil sites are shallow-rooted and short whereas on non-saline sites there is a inter-mixture of short and mid-grass species. Saline sites have "stunted" woody plant species less than 1.5 m tall, whereas on non-saline sites woody plants are taller and more dense.

Differentiation between primarily undisturbed saline and non-saline rangelands, in Starr County, is partially possible using film optical density readings from SKYLAB satellite imagery. Black-and-white film (SO-022; 0.60 - 0.70 μm) separated the low and high salinity sites best (6 out of 7 sites were correctly identified), compared with black-and-white infrared (EK-2424; 0.70 - 0.80 μm), color (SO-356; 0.40 - 0.70 μm) and color infrared (EK-2443; 0.50 - 0.88 μm) film, as evidenced by the least statistical overlap among film density means according to the Duncan Multiple Range Test (DMRT). Higher occurrence of bare soil background showing through the vegetation of saline sites caused higher optical density means than for non-saline sites for the 0.60 to 0.70 μm spectral region using the SO-022 film.

Differentiation among eight saline and non-saline soil sites in Cameron County, using black-and-white (EK-3414; 0.50 - 0.70 μm) and color (SO-242; 0.40 - 0.70 μm) film is not possible according to statistical results from both DMRT and correlation analysis. Further study seems warranted to determine whether mean density readings are related to lightness or darkness of soils located within study sites.

Linear correlation analysis showed that Bendix 24-band MSS data (aircraft) collected at 1,700 m and 4,800 m as well as SKYLAB and LANDSAT-1 MSS data (satellite) were significantly correlated to electrical conductivity readings. Electrical conductivity measurements correlated highest with MSS data difference and ratio between vegetated and bare soil areas as compared with vegetation or bare soil individually. Thus, differentiation among the eight saline and non-saline soil sites in Cameron County is partially possible using aircraft or satellite data using a measure of the vegetation and bare soil contrast as a saline soil indicator.

In Starr County, the best spectral band for detection of saline soil levels, using black-and-white SO-022 film, was in the 0.60 to 0.70 μm spectral region. In Cameron County, the best spectral bands for detection of saline soil levels, using aircraft data at 1,700 m and 4,800 m, SKYLAB, and LANDSAT-1 MSS data, were the 2.30 to 2.43 μm, 0.72 to 0.76 μm, 0.69 to 1.75 μm, and 0.70 to 1.10 μm spectral regions, respectively. Evidence using MSS data in Cameron County, at aircraft and satellite altitudes suggests that salinity influences vegetation versus soil spectral contrasts throughout the 0.375 to 2.35 μm range.

Relationships between optical density data and ECe measurements, such as found in the rangeland areas of Starr County, may be operationally useful to saline soil management in rangeland areas. Although these rangeland areas were mostly vegetal, optical density measurements appear to be related to the high natural occurrence of bare soil background showing through the vegetation in saline areas. These methods may also be useful for cultivated areas during summer months when there is more vegetation.

Relationships between ECe measurements and MSS digital data contrasts from vegetated versus bare soil areas may be operationally useful to saline soil management in cultivated areas such as Cameron County. Saline soil maps, developed using SKYLAB MSS data, indicate that soils of highest salinity occur near areas of native vegetation. These relationships probably will be most useful in winter months for cultivated regions where there are extensive areas of bare soil broken by areas of vegetation, but they may not apply in rangeland areas or in summer months for cultivated areas when there is more vegetation.

# SIGNIFICANT APPLICATIONS AND COST/BENEFITS

The results in Cameron County were used to evaluate and compare the potential cost and applications of photointerpretive, microdensitometer, and MSS saline soil detection. Comparisons among saline soil detection methods were made on the basis of: (a) potential for saline soil detection, and (b) cost related to the major operations involved in each saline soil detection system.

## Economic Considerations

The major operations involved in the saline soil detection study that cost analyses were based on for all methods are:

I. Film or CCT acquisition

II. Film or CCT data preprocessing
   A. Duplication of CCT
   B. Merging CCT
   C. Summarizing CCT
   D. Determining film density readings
   E. Editing film density paper tapes
   F. Gray mapping for film and CCT
   G. Delineating study site for film and CCT
   H. Calculating site means for film and CCT
   I. Image enlarging for photointerpretation

III. Ground truth collection

IV. Data summary
   A. Analysis of variance
   B. Duncan's Multiple Range Test
   C. Linear correlation analysis
   D. Generating saline soil computer maps
   E. Photointerpretation

V. Final Analysis
   A. Data tables
   B. Statistical tables
   C. Update current saline soil maps
   D. Report preparation

A number of assumptions were made to facilitate the cost comparisons of the saline soil detection methods used in this study. The costs of two of the major operations, ground truth collection and final analysis, were assumed to be approximately the same for all methods. Thus, only the major operating costs for film on CCT acquisition, film or CCT data preprocessing, and data summary were cost compared for each method. Investments for equipment and computer program development were not considered in cost comparisons. Since none of these methods has been used in a real operational sense (the photointerpretation method has not been used operationally or evaluated as part of this study) cost comparisons given are based on the current best estimate of rates that would be charged to a hypothetical saline soil management customer for the work performed in this study (excluding equipment, program development, ground truth collection, and final analysis costs).

## Applications

Photointerpretation was not evaluated in depth for the saline soil study in Cameron County, because inspection of SKYLAB film showed that it was not possible to visually detect the vegetation with bare soil contrast that was significantly correlated to SKYLAB, LANDSAT-1, and aircraft MSS data among saline soil sites in cropland areas during winter (December, 1973). However, it should be possible to visually detect the bare soil background showing through vegetation in saline areas, similar to rangeland areas (Starr County), during spring and summer. Thus, photointerpretative methods for saline soil detection in cropland areas should be possible in the spring and summer, whereas using MSS data and possibly film optical densities, saline soil detection may be possible throughout the year.

Saline soil mapping, based on linear correlation equations relating aircraft or satellite MSS data to salinity measurements, could be calibrated directly in terms of electrical conductivity (ECe) readings whereas photointerpretative methods can not. This application of MSS data to saline soil mapping could potentially produce new information because current saline soil maps could be updated on a frequent periodic basis. These updated saline soil maps, calibrated in terms of ECe readings could be used to show map contours that indicate salt limitations of forage crops (4.0 mmhos/cm), moderately salt-tolerant species (8.0 mmhos/cm), and highly salt-tolerant species (12.0 mmhos/cm).

## Cost/Benefits

The best estimates for the comparative costs of the various saline soil detection methods used in Cameron County, Texas are presented in Table 14. These costs are a summary of detailed considerations of the cost per CCT (\$120/CCT with recorded MSS data), computer time and rate (\$30/hr), and operator time and rate (\$5/hr) for film and data preprocessing operations only.

Aircraft MSS cost at 1,700 m was the highest, primarily because of the greater numbers of CCT involved, while photointerpretative and satellite costs were the lowest. Thus, any advantage gained in more accurate saline soil mapping at low aircraft altitudes may be offset by higher cost. Saline soil detection studies of this report indicate that satellite may provide results as good as aircraft results at lower costs. The new information that may be provided through calibrated salinity data (in terms of ECe readings) may mean that satellite MSS data could evolve into a more attractive saline soil detection system than photo-interpretative methods and could result in an overall cost savings to saline soil management.

Table 14. Best estimates for the comparative costs of various saline soil detection methods used in Cameron County, Texas (December 1973).

| Saline soil detection methods | Film or CCT acquisition | Film or CCT data preprocessing | Data summary | Total | Cost per acre |
|---|---|---|---|---|---|
| SKYLAB film photointerpretation | -- | $ 420 | $1,120 | $1,540 | $0.022 |
| SKYLAB film densitometry | -- | 1,720 | 90 | 1,810 | 0.026 |
| SKYLAB MSS | $ 240 | 288 | 200 | 728 | 0.011 |
| LANDSAT-1 MSS | 240 | 288 | 200 | 728 | 0.011 |
| Aircraft MSS (1,700 m) | 2,280 | 2,098 | 200 | 4,578 | 0.066 |
| Aircraft MSS (4,800 m) | 720 | 668 | 200 | 1,588 | 0.023 |

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